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THE SAULT STE. MARIE BRIDGE.

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The completion of "The Sault Ste. Marie Bridge" adds one more to the number of great International bridges connecting Canada and the United States, and forms the connecting link between the Canadian Pacific Railway and the network of roads traversing the Western States.

In the autumn of 1865 it was decided, by the Sault Ste. Marie Bridge Co., to build a bridge across the St. Marie River at the "Soo," and a party was organized to make the preliminary surveys, from the results of which it was decided to construct the bridge at the upper end of the St. Marie's Rapids, where the smooth water of the Lake commences to break away over the rocky bed of the river. The bottom is formed of smooth, level sand stone of the Potsdam formation, perfectly bare of gravel or *debris*, with the exception of Pier No. 1, where a considerable deposit was formed. In the winter of 1886-7 the contract for the construction was awarded to B. G. Reid, who the year before completed the St. Lawrence Bridge. Early in May the contractor and the engineering party arrived at "the Soo," and the work of triangulation commenced, and here it may not be out of place to go a little into the general detail of accurately determining the position of the piers.

The first operation was the measurement of a base line and the calculations of angles. The most scientific and practical method of setting out piers is by means of angles from a measured base, direct measurement by a long wire has been advocated by some engineers, but the experience of the author on this method has not been satisfactory. It may appear a very simple matter to measure 700 or 800 feet on a wire, and then transfer this distance between two points supported only at the ends, but the result of such is often unreliable, as was experienced by the engineers at the Forth Bridge. For distances of 400 or 500 feet, with great care, accurate results can be obtained, as the sequel will show.

In setting out by angles, the instruments used will first be discussed; these are three in number,—a transit, steel tape and picket. The transit should not be less than 8" diameter, reading to 10 seconds. The one used at the St. Lawrence bridge and "the Soo" was of this description, made by Hammersly of London, and furnished with a very powerful glass and long sensitive level underneath the telescope. There was no vertical arc, but simply the ordinary clamp screw, on this instrument five seconds could be estimated. For distances over 3,000 feet the author would recommend a 12 inch instrument, such as that used at the Forth Bridge, or better a 16 inch reading to five seconds. The author also thinks it would be an advantage to have the upper plate moved by a wheel attached to it, working into teeth set near the outer rim of the lower plate, thus ensuring a relative motion between the plates, and avoiding the danger of moving the lower plate when the upper plate is moved round, as this is one of the most serious causes of error in taking angles. The glass should be such as to show an ordinary picket clearly at a distance of one mile, so that the hairs can be set on an object to one inch at that distance. Accuracy of graduation is also one of the essentials. The transit above mentioned weighed about 40 lbs., and when not used on a fixed pedestal, was attached to a heavy wrought iron tripod weighing 80 lbs.

The next instrument is the steel tape. At the suggestion of the author the company ordered from Chesterman, England, a tape of heavy steel 500 feet long, and the result shows the accuracy of the work done with it.

Thirdly, we come to the picket, or centre used. These were designed by the author for the "Soo Bridge." They were made of 2 inch gas pipe, about seven feet long; the lower end being screwed into a socket formed like a fork, the two prongs of which rested on the hub, the centre of the pipe being placed accurately over the nail by means of a plumb bob and line, the line being fastened to the centre of the upper end and the plumb bob swinging in the fork below, thus ensuring the centre to be both exactly vertical and on the nail. The picket was then secured by four wires fastened to the upper end and two stakes driven into the ground; these wires could be adjusted for length by several screws, such as are used to tighten the ordinary buck-saw frame. The pickets were painted white, and a black band placed at a little distance behind to make them more distinct.

Now, in selecting a base, it is preferable to have one on either side of the river; one half of the piers being laid out from one and their positions checked from the other; a most satisfactory check on the work being to calculate one base from the other.

Of course the more level the ground is the better, and if at all possible each end of the base should be visible from the other, but it often happens that level ground cannot be had. The base for the St. Lawrence Bridge was measured with an ordinary 100 foot steel tape, laid on strips of board supported by hubs driven in about ten feet apart, and the ends cut off to a level. Where the ground fell away a lower set of levels were taken, and the distance plumbed down at each break; this was done with great accuracy, but considerable time was spent at it. By careful measurement the error should not exceed $\frac{1}{1,000,000}$. This base was measured before the author took charge of the St. Lawrence Bridge. The plan adopted at The Soo was to drive in stakes $1'' \times 2''$ ten feet apart, exactly in a straight line along the base from a front 25 feet above the centre line of the bridge to the point at which the transit was to be placed. A line was taken along the stakes, regardless of levels, from one point to the other, and large nails driven into the stakes to support the tape. At every 500 feet a firm staging was built, on which the exact 500 feet was marked, and the tape moved on to its next position, and so on till the base was measured. This was repeated three or four times, the tape being always stretched by a spring balance under a tension of 50 lbs. The 500 foot tape while under this tension was checked with a 100 foot standard tape, the latter having been previously compared with the standards used by the company who were to build the superstructure of the bridge. The temperature was also carefully noted, and the length of the base reduced to a normal temperature of 60° F, and also corrected for slope. At the St. Lawrence Bridge a good base was obtained on both sides of the river, and the accuracy of the triangulation and measurements checked by calculating one base from the other, but at "The Soo" the two bases had to be measured on the south side. When the base was fixed, a solid oak post was placed at one end and a hub let into the rock at the other. The large transit was set on this post, and all the angles to the several piers laid off from it. An ordinary transit was set over the other, this point being as was stated 25 feet above the centre line of the bridge, and a corresponding centre set up on the opposite side of the river, exactly 25 above the centre line of the bridge on which the cross hairs of the transit were set. All the piers were laid off from this upper line. The object of keeping this line 25 above the bridge was to clear all derricks, scows, etc., at the same time admitting of a point being fixed on the upper end of the caissons.

The distance across the river at "The Soo" was about 3,000 feet. This being calculated from two entirely independent sets of data, the results checked *to the tenth of an inch*, the whole of the work, including measurement of basis, taking of angles and calculations, did not occupy one week. This calculated distance agreed with the taped distance, after the construction of the bridge, to $1\frac{1}{2}$ inches. The author may add that the calculated distance and the measured distance on the St. Lawrence bridge agreed to $2\frac{1}{2}''$ on a distance of 3,700 feet. The base used for setting out the piers at "The Soo" was about 1,900 feet long. A small shanty was built at either end to protect the instruments, and on the roof of these, exactly over the centres, two pickets were set, of the kind previously described. These were checked from time to time by means of the plumb bob. The instrumental work required much care and patience. All the angles had to be repeated several times to eliminate all eccentricity in the centering of the transit.

It was found that the lower plate of the transit was liable to slip while moving the upper plate; thus after taking the 3 angles of a triangle, the sum was usually less than 180° by some seconds. To avoid this error the following method was adopted: Zero of the transit was first set on the far end of the base, and the upper plate moved till the hairs intersected the picket on the far side of the river. The angle was then noted, and the upper plate moved round in the same direction till the hairs intersected the first picket. Now, if the vernier did not read zero, it was evident the lower plate had shifted, and the operation had to be repeated. When this angle was satisfactorily recorded, the vernier was set at 10°, the hairs set on the first picket and the upper plate moved round to the second picket, the angle read, then moved round to 10° and checked to see if the hairs were on the first picket, and so on, increasing by 10° each time, then the average was taken. By this means great accuracy was attained, any small discrepancy of a second or two was distributed between the three angles in proportion to their size. In setting out the piers the same precautions were taken. In reading the verniers, a sheet of white paper was placed close to the plate, and the reading taken through a small hole cut in the paper. This paper threw a shade on the vernier, and the graduations could be seen with great distinctness. Close beside each of these shanties, a signal was erected, which could be worked by the man at the transit, without taking his eye from the instruments as the caisson approached its proper position. A man on board held up a picket, which was immediately signalled into its exact position by the transitman, and by this means the men who guided the caisson were enabled to see which way it had to go without any confusion or mistake. When the caisson was placed by the transits, its position was verified with a steel wire of given length, usually the length of a span. This wire was about $\frac{1}{8}$" diameter, the exact length marked on it by a loop soldered on at each end; one loop of the wire was brought exactly over the starting point by means of a long adjustable screw arrangement, the other was carried in the boat to the caisson and strained to 200 lbs. and the exact distance marked. Very correct measurement can be made in this way, but it is necessary constantly to check the wire under strain with the standard tape, and also when not in use to roll it on a reel made specially so as to prevent the wire getting bent. At the St. Lawrence Bridge, the 408 ft. cantilever spans were measured in this way, and when the iron work was connected, the measurements agreed exactly on one of the 408 feet spans, and on the other there was a discrepancy of only $\frac{1}{4}$ inch.

In setting out piers from a base line, the question will arise as to the length of base which will give the most accurate results, assuming that the transit reading may be liable to an error of (a seconds) when (a) may be 1 to 5. It may be shewn mathematically that this length should be equal to the length from the base to the pier measured along the base, or that the angle below the base line and a line from the transit to the pier should equal that between this line and the bridge line. This would shew that theoretically the best results are obtained by having a separate point on the base for setting off each pier. The author believes that this was carried out at the International Bridge at Buffalo.

The next operation was to level across the river; this was done by placing three of the best levels on each side of the river, and reading on a large rod graduated to $\frac{1}{10}$ of a foot held up on the opposite shore; when the three readings were taken the rods were held up at as nearly as possible equal distances, but on the same shore. Thus the errors of curvature and refraction were neutralized by these equal sights. The error in levelling by this method should not exceed $\frac{1}{100}$ in 3,000 feet, when the levels were transferred across two stands for the large transit wire set up just above the bridge line, one on either side of the river, and opposite each a target placed, whose centre was exactly on the same level as the cross hairs of the transit when set on the opposite stand; thus by setting up the instrument and directing its cross hairs on this target, a correct level was ensured, the only source of error was in certain states of the weather, the diffraction was so great as to cause an error of $\frac{1}{10}$ of a foot in the line of levels; but slight errors in levels, except in the case of continuous girders, are of little consequence, much less than errors of distance, as the appearance of a bridge not sitting fair on the centre of the piers has a very bad effect. During the time occupied in triangulation, the contractor was employed building a temporary wharf for landing stone and other

material and excavating foundations for abutments. Most of the plant used in the construction of the St. Lawrence Bridge was shipped to "The Soo," and comprised two tugs, 22 scows, three of which were furnished with steam derricks, two pumps, six large anchors, two clam shell dredges, and other but less important implements used on such work.

The depth of the water on the site of the bridge varied from 2 to 12 feet.

Although the extreme rise of the river, except after a westerly gale, does not exceed 2½ feet, it is at any time liable to 1½ feet rise in less than an hour, due to some wave motion of the Great Lakes. The swiftest current is where the water is deepest towards the Canadian side, and attains a velocity of 9 miles per hour. The shallowness of the water rendering it impossible to bring the tugs within less than 300 feet of the piers, the scows and caissons had to be lowered down by ropes.

The plan of foundation is similar to the St. Lawrence Bridge, namely, caissons with water-tight sides of 12″ × 12″ timber, without any bottom, the sides scribed to fit the rock. The caissons were so designed as to allow a space of 4′ 6″ between the timber and the sides of the piers. A curtain of canvass was nailed round the inside of the caisson to check any current while depositing the concrete.

The concrete was formed of sand and Portland cement in equal quantity, to which was added as much broken stone as the mortar thus made would take. This concrete was deposited by the same boxes as were used at the St. Lawrence bridge, and described in a paper by the author.* The depth of the concrete was never less than half the depth of the water with a minimum depth of two feet. The second day after the concrete was deposited the caisson was pumped dry, the bottom levelled, and masonry commenced. In building with timber caissons and concrete bottoms, the depth of the latter should not be less than ⅓ the depth of the water, with a minimum depth of two feet. Less concrete than this is apt to cause troublesome leaks, and the concrete box should hold two cubic yards. The masonry of the small bridge on the Canadian side was commenced June 9th; and the north abutment of the main bridge on June 2nd, but no masonry was laid in the river piers until August 9th; as much time was lost in negotiating with the United States Government as to duty on plant and material, etc. The last of the masonry of the Main Bridge was laid October 7th.

The work proceeded rapidly and smoothly without serious mishaps or accidents of any kind, the experience gained on the St. Lawrence Bridge by the men employed proving of great service. No. 1 Pier was the most tedious, as a large quantity of gravel had to be dredged off by means of a large rake attached to a long handle, operated from scows anchored over the foundation, any remaining gravel being cleared off after the caisson had been placed. The most troublesome and costly foundation was the centre pier of the Swing Bridge. This had to be carried down 22 feet below water level through seamy rock, in anticipation of the enlargement of the canal at some future date. The pier was circular, with a diameter of 30 feet, the excavation being several feet wider; leaving only about 20 feet of rock between the pier and the canal, through which the water poured like a river, requiring the constant use of two large rotatory wrecking pumps until the masonry reached the water level. The stone used in the swing bridge and the bridge at Canal Street was Ohio sandstone, the remainder being white limestone from the Owen Sound Quarries. The general plan of piers and abutments are similar to those of the St. Lawrence Bridge, the piers of the Main Bridge all being 10 feet wide on top.

The following is a brief outline of the bridge: Commencing on the Canadian side, the approach to the bridge is of timber trestle 1500 feet in length, with two spans of iron crossing a small branch of the river, then the main bridge consisting of 10 spans of 242 feet each. Pin connection through girders, then 400 feet of bank which reaches the north abutment of the swing bridge over the St. Marie canal. The swing has a total length of 396 feet, crossing the canal at an angle of about 60°, then another bank of 200 feet, and a plate girder over Canal Street reaches the southerly limit of the Bridge Co'.s property.

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* Vol. I., Part I., page 39, Transactions Can. Soc. C. E.